

GEOCHEMICALLY HETEROGENEOUS MARTIAN MANTLE INFERRED FROM THE LEAD ISOTOPE SYSTEMATICS IN THE TWO DEPLETED SHERGOTTITES YAMATO 980459 AND DAR AL GANI 476. R. Moriwaki^{1*}, T. Usui², M. Tobita¹, and T. Yokoyama¹, ¹Dept. of Earth and Planet. Sci., Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan (*moriwaki.r.ab@m.titech.ac.jp). ²Earth-Life Science Institute, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan.

Introduction: Geochemical studies for Martian mantle have played key roles for understanding the early geochemical evolution of the terrestrial rocky planets. Previous studies on the radiogenic Sr-Nd-Hf isotope systematics of shergottite meteorites demonstrate that the Martian mantle has geochemically heterogeneous structure that originated from the fractional crystallization during the Martian Magma Ocean (MMO) [e.g., 1]. Because the depleted shergottite source reservoir derived from the early-stage cumulates in the MMO [1], geochemical studies on the depleted shergottites provide a means to understand the early geochemical evolution of the Martian mantle.

Lead isotope systematics has been widely used as a powerful geochemical tracer for examining the Earth's crust-mantle evolution [e.g., 2], although it has not been well applied to the Martian mantle. There are only two reliable Pb isotopic data for the depleted shergottite source reservoir, which were obtained from Pb isotope analyses of Queen Alexandra Range (QUE) 94201 [3] and Tissint [4]. To characterize the geochemical heterogeneity in the depleted Martian mantle based on the Pb isotope systematics, this study determine Pb isotopic compositions and μ -values ($^{238}\text{U}/^{204}\text{Pb}$) in the source reservoirs of the two depleted shergottites Yamato (Y-) 980459 and Dar al Gani (DaG) 476. These two samples were selected because their reported initial $\epsilon^{143}\text{Nd}$ compositions ($\epsilon^{143}\text{Nd} = 36.9 \pm 2.2$ for Y-980459 [5]; $\epsilon^{143}\text{Nd} = +36.6 \pm 0.8$ for DaG 476 [6]) are distinct from those of the QUE 94201 ($\epsilon^{143}\text{Nd} = +47.6 \pm 1.7$ [7]) and Tissint ($\epsilon^{143}\text{Nd} = 42.2 \pm 0.5$ [8]).

Analytical Method: We prepared whole-rock powders from Y-980459 and DaG 476 fragments with a highly pure quartz mortar and pestle. Each of these fragments was obtained from a sample interior to avoid terrestrial alteration/weathering. We followed the analytical procedures described in [4]. Five-step sequential acid leaching experiments (L1: H₂O, L2: acetone, L3: 0.5 M HBr, L4: 1 M HF, L5: 5 M HCl) were conducted on these whole-rock powders in order to remove the secondary contaminated Pb. One-tenth of each leachate and the final residue were used for trace element analyses, including U and Pb concentration analyses, with a quadrupole type ICP-MS instrument (X series II, Thermo-Fisher Scientific) at Tokyo Tech. Lead isotope analyses were conducted with TIMS (Triton-plus, Thermo-Fisher Scientific) at Tokyo Tech.

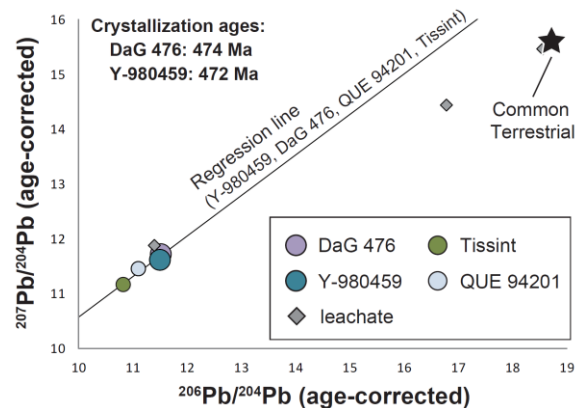


Fig. 1 Age-corrected initial Pb isotopic compositions of Y-980459 and DaG 476. The compositions of QUE 94201 [3], Tissint [4] and terrestrial Pb [9] are also shown.

We conducted Pb isotope measurements for the final residue fractions (R) from both of the Y-980459 and DaG 476 whole-rock powders. The Pb isotopic compositions of the L3 (0.5 M HBr) and L5 (5 M HCl) fractions were also measured because large amounts of Pb were distributed to these leaching fractions. The age-corrected initial Pb isotopic compositions were calculated based on their measured Pb isotopic compositions, U/Pb ratios, and the crystallization ages reported in previous studies. We employed the crystallization ages of 472 Ma [5] for Y-980459 and 474 Ma [6] for DaG 476, both of which were obtained by the ^{147}Sm - ^{143}Nd chronology.

Results: Our age-correction calculation for the residue fractions yielded initial $^{206}\text{Pb}/^{204}\text{Pb}$ isotopic ratios of Y-980459 and DaG 476 to be 11.484 ± 0.050 and 11.500 ± 0.063 , respectively (Fig. 1). These initial Pb isotopic compositions are indistinguishable from each other within analytical uncertainties, whereas they are distinctly more radiogenic than the initial Pb isotopic compositions of QUE 94201 [3] and Tissint [4]. These four depleted shergottites define a regression line that does not pass through the Pb isotopic composition of the common terrestrial component (Fig. 1 [9]).

Discussion: The age-corrected initial Pb isotopic compositions of Y-980459 and DaG 476 unlikely reflect a mixture with terrestrial contaminated Pb. This assertion is justified by the following two reasons. First, the regression line from the four depleted shergottites Y-980459, DaG 476, QUE 94201 [3], and Tissint [4] does not pass through the Pb isotopic composition of

common terrestrial component (Fig. 1). This observation indicates that the distinct Pb isotopic compositions among these depleted shergottites do not result from terrestrial contamination but reflect their pristine geochemical signatures. Second, the initial Pb isotopic compositions from Y-980459 and DaG 476 are indistinguishable from each other within analytical uncertainties. Their uniform Pb isotopic composition is consistent with the fact that they have similar initial $\epsilon^{143}\text{Nd}$ compositions [5, 6]. It is unlikely that the different weathering/alteration processes on the Antarctic and desert surface results in the same Pb isotopic compositions between these two depleted shergottites.

We calculated μ -values of the Y-980459 and DaG 476 source reservoirs based on their age-corrected initial Pb isotopic compositions and the two-stage mantle evolution model [4]. We assumed the Pb isotopic composition of Canyon Diablo Troilite (e.g., $^{206}\text{Pb}/^{204}\text{Pb} = 9.307$ [10]) as the solar initial at 4.567 Ga and the Martian silicate differentiation age of 4.504 Ga [11]. Our two-stage model calculation indicates that the Y-980459 and DaG 476 source reservoirs have μ -values of 2.32 ± 0.06 and 2.33 ± 0.07 as the present sources, respectively (Fig. 2). These μ -values are higher than those of Tissint ($\mu = 1.62 \pm 0.09$ [4]) and QUE 94201 ($\mu = 1.81 \pm 0.01$ [3]) sources, but clearly lower than the μ -value of enriched shergottite source reservoir ($\mu = 3.98 \pm 0.02$) estimated from the Pb isotopic composition of an enriched shergottite Zagami [12].

The distinct μ -values among the four depleted shergottite source reservoirs suggest the geochemical heterogeneity in the depleted Martian mantle. The higher μ -values in the Y-980459 and DaG 476 source reservoirs are suggestive of their more incompatible-element-enriched signatures than those of the Tissint and QUE 94201 source reservoirs. These results are consistent with the variation of $^{147}\text{Sm}/^{144}\text{Nd}$ ratios of

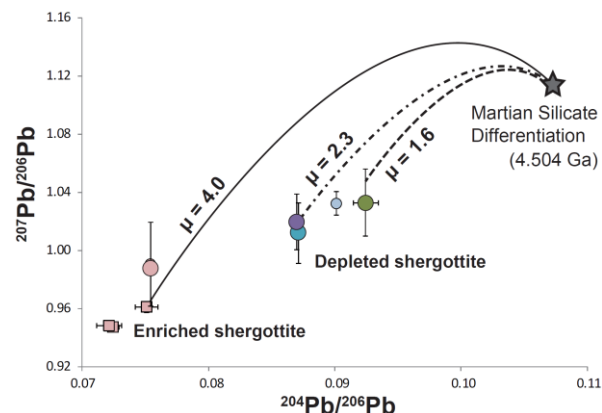


Fig. 2 Lead isotopic evolutions in the Y-980459 and DaG 476 source reservoirs. Evolution curves of the Tissint [4] and Zagami [12] source reservoirs are also shown. Colors are coded to Figure 1. Squares show the data from ion-probe analysis [13].

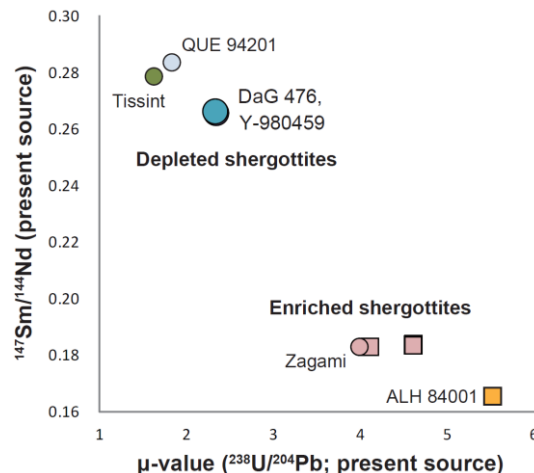


Fig. 3 The μ -values and $^{147}\text{Sm}/^{144}\text{Nd}$ ratios in the shergottite source reservoirs. Symbols and colors are coded to Figures 1 and 2.

the individual source reservoirs calculated from the initial Nd isotopic compositions (Fig. 3 [5-8]). The correlation between the μ -values and $^{147}\text{Sm}/^{144}\text{Nd}$ ratios is explained by a mixture between two end-member components in the Martian mantle. The DaG 476 and Tissint source reservoirs also show the distinct signatures in the short-lived isotopic compositions of $\epsilon^{182}\text{W}$ [14], suggesting that the different isotopic compositions in their source reservoirs originated from the primary Martian differentiation at ~ 4.5 Ga. Therefore, we conclude that the mixture between two end-member mantle reservoirs that formed during primary Martian differentiation generated the geochemical heterogeneity in the depleted Martian mantle.

Conclusions: We determined the μ -values in the Y-980459 and DaG 476 source reservoirs to be 2.32 ± 0.06 and 2.33 ± 0.07 , respectively. These μ -values are distinct from those of the Tissint and QUE 94201 source reservoirs, suggesting the Pb isotopic heterogeneity in the depleted shergottite source mantle. This geochemical heterogeneity derived from the primary Martian differentiation occurred at ~ 4.5 Ga.

References: [1] Borg, L. E. and Draper, D. S. (2003) *MAPS* 38, 1713-1731. [2] Stracke, A. et al. (2005) *GGA* 6, No. 5. [3] Gaffney, A. M. et al. (2007) *GCA* 71, 5016-5031. [4] Moriwaki, R. et al. (2017) *EPSL* 474, 180-189. [5] Shih C. -Y. et al. (2005) *AMR* 18, 46-65. [6] Borg, L. E. et al. (2003) *MAPS* 38, 3519-3536. [7] Borg L. E. et al. (1997) *GCA* 61, 4915-4931. [8] Brennecka G. A. et al. (2014) *MAPS* 49, 412-418. [9] Stacey, J. S. and Kramers, J. D. (1975) *EPSL* 26, 207-221. [10] Tatsumoto, M. et al. (1973) *Science* 22, 1279-1283 [11] Borg, L. E. et al. (2016) *GCA* 175, 150-167. [12] Borg, L. E. et al. (2005) *GCA* 69, 5819-5830. [13] Bellucci, J. J. et al. (2015) *JGR-Planets* 120, 2224-2240. [14] Kruijer, T. S. (2017) *EPSL* 474, 345-354.